SOME DIFFRACTION PHENOMENA; SUPERPOSED FRINGES.[1]

By CHARLES F. BRUSH.

(*Read April 19, 1913.*)

Fresnel observed that diffraction fringes, outside the shadow, are not affected by the thickness or shape of the diffracting edge so long as the latter is smooth and straight; and cited, as an instance, the back and edge of a razor, which gave identical fringes under the conditions of his experiment. Presumably he observed the fringes as developed several decimeters, or even meters, from the diffracting edge in the usual way.

I have found, however, that when the fringes are observed within a millimeter or two of the diffracting edge, by means of a microscope, they are very greatly influenced in brightness and sharpness by the contour of the edge.

In most of my experiments I have used cylindrical edges in order that their shape and curvature might be accurately known. I have used fine wires grading up from 0.02 of a millimeter in diameter to fine needles, thence to medium and large needles, and small, medium and large brass rods and tubes, always with a smooth surface. The fine wires and needles were screened on one side to confine diffraction to the other side only.

In the diagram of my apparatus *A* represents the source of light, which conveniently may be a short section of a tungsten lamp filament; *B* is a spectrometer slit parallel with the lamp filament and very nearly closed. *C* is the diffracting screen located 15 or 20 cm. from the slit, with its edge adjusted parallel with the slit by turning the stage of the microscope *D*. *D* is a microscope provided with a 5.0 or 2.5 cm. objective and a strong eyepiece giving a magnifying

[1] Presented in preliminary form before The American Asociation for the Advancement of Science, December 30, 1912.

power of 100 to 200 diameters. The focal plane of the objective is usually adjusted near the diffracting edge as indicated by the dotted line, and it must be borne in mind that this is where the fringes are seen.

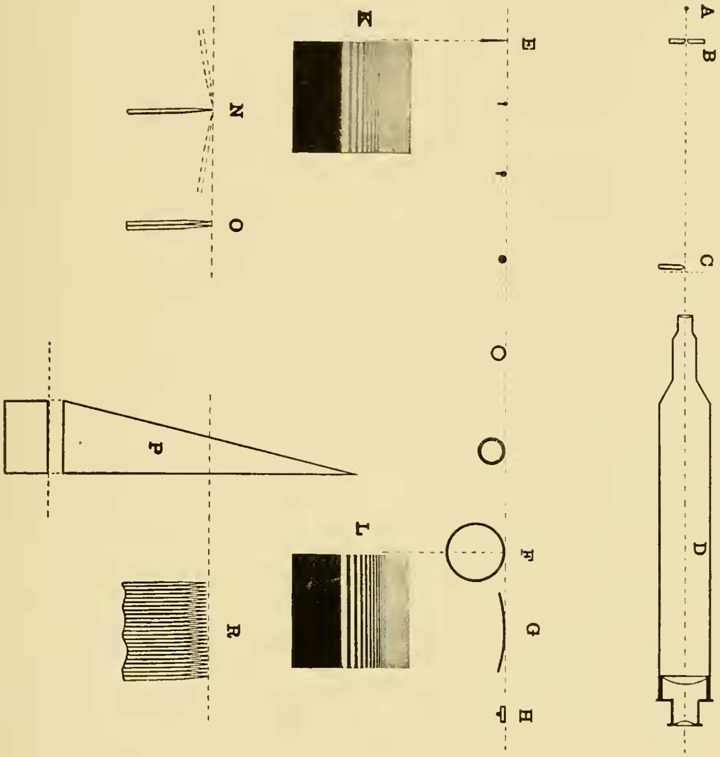

FIG. 1.

From *E* to *F* a series of cylindrical edges of progressively increasing radii is indicated. *E*, however, is a sharp razor blade, and the fringes projected by its edge are shown, greatly magnified, at *K*. They are weak, few in number and hazy in outline; but these conditions are not due to any irregularity of the edge. When a fine wire is used the fringes are distinctly better. Every time the radius of the cylindrical edge is doubled, the fringes are unmistakably brighter and sharper. *L* indicates the fringes produced by the cylinder *F*, of 22 mm. radius. They are very bright and sharp, and nearly free from color. From 12 to 15 may be seen. The curved plate *G*, of many cm. radius, gives fringes perceptibly brighter than *F*.

When the radius of the cylindrical edge is rather less than one millimeter, all fringes disappear if the focal plane is advanced sufficiently to coincide with the median plane of the edge, as would be expected. But when the radius is a millimeter or more, sharp, narrow fringes may be seen with the focal plane in this position, and these fringes grow broader and more numerous as the radius of the diffracting edge is increased. Evidently they are formed by elements of the cylindrical edge lying beyond (toward the light) the element in the median plane. If, now, the focal plane of the microscope is slowly advanced toward the light, these fringes slowly retreat behind the edge without greatly changing their spacing. They remain visible for some distance behind the edge because the angular aperture of the microscope objective enables the observer to see around and beyond the edge to some extent. Upon reversing the movement of the focal plane the fringes move laterally from behind the edge until the median plane is reached, when the lateral movement stops abruptly and the fringe pattern simply broadens out as the retreat of the focal plane continues.

I am led to the belief that the very greatly enhanced brightness of the fringes produced by the diffracting edge of large radius as compared with the razor edge, is due to the superposition of a number of diffraction fringe patterns which are almost, but not quite, in register. This view is supported by experiments illustrated in diagrams *N* and *O*.

N shows a razor blade greatly enlarged. It makes not the slightest difference in the fringes whether the blade is in the full line position shown, or in either of the dotted line positions, the essential condition being that the light undergoing diffraction shall not strike the beveled side of the blade.

At *O* two razor blades are shown clamped together with their edges as close as possible (about 0.2 mm.), and as nearly as possible in the same plane. The combination is adapted to be rotated slightly about the line of one of the edges as an axis by means of a tangent screw, so that the edge nearer the light may be withdrawn very slightly below the plane of the incident beam which strikes the other edge. When this adjustment is just right the brightness of the one-blade fringes is approximately doubled, clearly indicating that two superposed fringe-patterns are formed. It appears that twice as many elements of each wave front are affected.

We may regard the cylindrical diffracting surfaces as consisting of a great many parallel elements, each acting as a diffracting edge and producing its own fringe pattern which is superposed on those of the other elements. This superposition of fringes is not apparent when they are viewed in the usual way, *i. e.*, in a plane far removed from the diffracting edge, because nearly all of the patterns have their origins so far behind (toward the light) the tangent element of the edge that they are hidden by it. The method of viewing the fringes herein described, however, enables the observer to see these hidden fringe patterns, as already pointed out.

Measurements, the details of which need not be gone into, show that in the case of the cylinder *F*, of 22 mm. radius, the width of the strip of surface involved in producing the best and brightest fringe pattern is about 1.5 mm., though 0.9 mm. gives all but the extreme lines. Smoking the surface of the cylinder makes very little difference in the brightness of the fringes, and the slight loss observed is accounted for by the roughening of the surface.

Careful eyepiece micrometer measurements of the spacing of the fringes formed by the razor edge *E*, and a cylinder of small radius agree perfectly with the theoretical spacing of diffraction fringes. But with the large cylinder *F* (and still more so with the curved surface *G*) the spaces diminish less rapidly toward the outer margin of the pattern and the outer fringes lose their sharpness, because the many superposed fringe patterns which form the composite pattern observed are not quite in register; so that beyond 12 or 15 fringes many maxima and minima so far coincide that no more lines are seen.

The reason why the numerous patterns are not perfectly in register becomes clear when we consider that they have their origins at different distances from the focal plane of the microscope, and hence are seen spread to different extents. This discrepancy is partially offset by the lateral displacements of the origins due to the curvature of the diffracting surface, and the net result is that the composite pattern seen is brightest and sharpest in a few fringes only, the position of which may be shifted to some extent by shifting the focal plane.

Diagram H shows the end of a glass plate with optically plane polished upper surface 12 mm. wide, bounded by straight edges. It may be regarded as a portion of a cylinder of infinite radius, constituting one end of a series of curved diffracting surfaces of which the razor edge E is the other limit. The plate is adapted to be slightly rocked by tangent-screw mechanism so that its face may be adjusted very nearly parallel with the incident light.

When thus adjusted Lloyd's so-called "single-mirror interference fringes" are brilliantly shown, and the focal plane of the microscope may be moved through a wide range over the face of the mirror without disturbing the fringes in any way, proving that they have their origin on the surface of the mirror or plate, and not at its edges. The first one or two dark bands are very black and sharp, and the others show more and more color, until the fifth and beyond are all color. Only seven or eight fringes can be seen, and their spacing is sensibly uniform, as with ordinary interference fringes.

I shall now endeavor to show that these so-called "single-mirror interference fringes" are not due to interference of light reflected at grazing incidence with contiguous rays not reflected, as commonly supposed, but are superposed diffraction fringes like those already described.

Considered from this point of view, the origins of the many superposed fringe patterns all lie in the same plane and very nearly in the line of sight, and hence, owing to unequal spreading of the several patterns as already explained, some maxima begin to overlap some minima not far from the major edge of the composite pattern. Therefore few fringes are seen, and most of them are colored.

The extreme blackness of the dark bands forcibly suggests superposition of many minima. If the very small angle between the face of the mirror and the incident beam of light is gradually increased by slowly turning the tangent screw, the fringes move closer together and lose their uniform spacing and most of their color, while the sharpest and blackest bands move further out in the pattern.

The width of the mirror, in the line of sight, may be reduced to 2 mm. without affecting the fringes in any respect; but with continued further reduction the fringes progressively lose their color, increase in number, and assume the characteristic spacing of diffraction fringes strongly reinforced by superposition of patterns, when the width is only a fraction of a millimeter.

These phenomena are beautifully shown by means of the device illustrated in diagram *P*. The plane glass mirror is here shown both in plan and elevation and enlarged to the scale of the razor blades *N* and *R*. It is in the form of a thin wedge about 12 mm. long and 3 mm. wide at the base, giving a triangular face. The line of sight is indicated by the dotted line.

Having adjusted the face of the mirror so as to produce the Lloyd fringes, and with the near edge of the mirror in the focal plane so as to prevent any edge effect, the mirror is very slowly moved on the microscope stage across the line of sight toward the point, without change of angle with the incident light. During this movement all the last described effects are developed. I may add that smoking the face of mirror *H* or *P* does not materially affect the brilliancy of the fringes.

In view of the facts cited it seems clear that the so-called "single-mirror interference fringes" of Lloyd are superposed diffraction fringes, and are not due to reflection. But to remove all doubt the device shown in diagram *R* was constructed.

This consists of 24 paper-thin razor blades clamped together and forming a bundle about 4 mm. thick. It is essential that all the edges be accurately brought to the same plane. But inasmuch as the edges of the blades are not perfectly straight, this condition can be realized only in two lines across the edge of the bundle. To effect this adjustment, the edges of the blades, very loosely clamped together, were allowed to rest by gravity against two parallel straight glass rods about half the length of the blades apart, and then cautiously clamped tight. Great care was taken to avoid injury to the edges where they touched the rods, because it is only in these lines of contact, or very near them, that the effects to be described are produced. The glass rods were then removed and the bundle of blades was mounted and used in the same manner as the two-blade system *O* already described.

With this device, which precludes reflection, all the effects described in connection with the mirror *H* may be reproduced, differing only, and differing but little, in brilliancy. As only about half of all the edges (2 mm. across the edge of the bundle) are effective at any one time in producing visible fringes, it seems remarkable that the latter are so brilliant. But we must bear in mind that, say, twelve superposed fringe patterns will concentrate nearly all the light into the bright bands, leaving the dark bands nearly black; so that the contrasts should be nearly as strong as those produced by the far greater number of superposed patterns given by the mirror *H*.

The device *R* shows also something more of interest. Owing to the limited number of patterns formed, failure in registry may be seen at some points as division of a normal black band into two narrower dark lines which merge when the tangent screw is slightly turned, or the focal plane slightly moved; and this phenomenon may be shifted to different parts of the composite pattern by continuing either or both of these adjustments. Thus relative shifting of various fringe patterns, each more or less reinforced, is made obvious.